PREPRODUCTION INITIATIVE
DIESEL EMISSIONS CONTROL DEVICE
FINAL REPORT

NAS JRB WILLOW GROVE, PA

1.0 INTRODUCTION

The U.S. Navy has adopted a proactive and progressive position toward protecting the environment and complying with environmental laws and regulations. Rather than merely controlling and treating hazardous waste by end-of-the-pipe measures, the Navy has instituted a program for pollution prevention (P2) to reduce or eliminate the volume and toxicity of waste, air emissions, and effluent discharges.

P2 allows the Navy to meet or exceed current and future regulatory mandates and to achieve Navy-established goals for reducing hazardous waste generation and toxic chemical usage. P2 measures are implemented in a manner that maintains or enhances Navy readiness. Additional benefits include increased operational efficiency, reduced costs, and increased worker safety.

The Navy has truly set the standard for the procurement and implementation of P2 equipment. The Chief of Naval Operations (CNO), Environmental Protection, Safety, and Occupational Health Division (N45) established the P2 Equipment Program (PPEP), through which both the Naval Air Systems Command Lakehurst (NAVAIR LKE) and the Naval Facilities Engineering Service Center (NFESC) serve as procurement agents under the direction of N45. P2 equipment is specified and procured under two complementary initiatives: the Preproduction Initiative (*i.e.,* technology demonstration) and the Competitive Procurement Initiative. The Preproduction Initiative directly supports both the Navy Environmental Leadership Program (NELP) for P2 shore applications and the P2 Afloat program, which prototypes and procures P2 equipment specific to the needs of ships.

This report provides an analysis of the procurement, installation, and operation of P2 equipment under the Preproduction Initiative. Technology demonstrations and evaluations are primarily performed under the PPEP Preproduction Initiative at two designated NELP sites—Naval Air Station (NAS) North Island and Naval Station (NS) Mayport. Additional sites, such as NAS JRB Willow Grove, have been added as required to meet specific mission goals. The program involves defining requirements, performing site surveys, procuring and installing equipment, training operators, and collecting data during an operational test period. The equipment is assessed for environmental benefits, labor and cost savings, and its ability to interface with site operations.

2.0 BACKGROUND

Navy ground support equipment (SE) performs vital functions in support of aircraft operations. Everything from electrical and hydraulic power to air conditioning can be supplied by the appropriate type of SE. In addition, tow tractors provide a vital service by positioning aircraft and other SE for takeoff, maintenance, and storage. Most tow tractors and many other types of SE are powered by diesel engines. During operation, diesel engines emit particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and sulfur oxides (SOx).

The quantity of SOx emitted by a diesel engine is directly related to the concentration of sulfur in the fuel used. Currently, the acceptable concentration of sulfur in fuel used by non-road diesel engines is 2,000 ppm (highway, marine, and locomotive fuels have different standards). Current regulations will require the use of low-sulfur diesel fuel (500 ppm sulfur) in non-road diesel engines by 2007 and ultra-low sulfur diesel fuel (15 ppm sulfur) by 2010. In addition to the environmental benefits of reducing SOx emissions, this reduction in sulfur content will allow the implementation of advanced emissions control systems (sulfur poisons the catalysts that the emissions control systems utilize) and is expected to reduce wear on some engine components.

The U.S. Environmental Protection Agency (EPA) and some state governments have set standards for the maximum quantity of the other pollutants emitted from non-road diesel engines. These standards are applicable only to new diesel engines; engines already in operation may continue to be operated. The specific standard applicable to a particular engine is dependent upon the horsepower of the engine, the model year for the engine, and some manufacturer decisions (e.g., whether to utilize engine Family Emissions Limits; participation in the Averaging, Banking, and Trading Program; when a model year begins; etc.).

Due to physical constraints in smaller diesel engines, as the quantity of NOx emitted is reduced, the quantity of HC emitted increases. For this reason, and because methane does not contribute to ground-level ozone pollution, the EPA set limits on the emission of "non-methane hydrocarbon (NMHC) plus NOx" instead of establishing limits on HC and NOx separately for some engine power bands. In general, methane represents approximately 2% of the total quantity of HC emitted from a diesel engine.

The following tables summarize the main requirements of the EPA's non-road diesel engine emissions control program. It should be noted that EPA changed the power bands for some engines between the Tiers 1 to 3 and Tier 4 standards. These changes were made because the non-road diesel engine market is worldwide and the changes allow harmonization between U.S. and European Union standards beginning with Tier 4. The first table below presents the emissions standards for Tier 1, 2, and 3 diesel engines. The Tier 1 to 3 standards may be found at 40 CFR 89.112. Additional requirements (such as opacity limits) and applicability provisions (such as engine family certification and provisions of the Averaging, Banking, and Trading Program) may be found in other sections of 40 CFR 89.

Engine Power (kW)	Tier	Model Year	PM (g/kW-hr)	NOx (g/kW-hr)	HC (g/kW-hr)	NOx + NMHC (g/kW-hr)	CO (g/kW-hr)
<8	1	2000	1.0	-	-	10.5	8.0
	2	2005	0.8	-	-	7.5	8.0
8 to <19	1	2000	0.8	-	-	9.5	6.6
	2	2005	0.8	-	-	7.5	6.6
19 to <37	1	1999	0.8	-	-	9.5	5.5
	2	2004	0.6	-	-	7.5	5.5
37 to <75	1	1998	-	9.2	-	-	-
	2	2004	0.4	-	-	7.5	5.0
	3	2008	0.4	-	-	4.7	5.0
75 to <130	1	1997	-	9.2	-	-	-
	2	2003	0.3	-	-	6.6	5.0
	3	2007	0.3	-	-	4.0	5.0
130 to <225	1	1996	0.54	9.2	1.3	-	11.4
	2	2003	0.2	-	-	6.6	3.5
	3	2006	0.2	-	-	4.0	3.5
225 to <450	1	1996	0.54	9.2	1.3	-	11.4
	2	2001	0.2	-	-	6.4	3.5
	3	2006	0.2	-	-	4.0	3.5
450 to <560	1	1996	0.54	9.2	1.3	-	11.4
	2	2002	0.2	-	-	6.4	3.5
	3	2006	0.2	-	-	4.0	3.5
> = 560	1	2000	0.54	9.2	1.3	-	11.4
	2	2006	0.2	-	-	6.4	3.5

The table below presents the final emission standards for Tier 4 non-road diesel engines (as of the 2014 model year). These requirements may be found at 40 CFR 1039.1 and 1039.101. The Tier 4 emission limits for some power bands and pollutants are to be phased in over several years, which will result in some engines meeting these requirements before the 2014 model year. The transition standards are detailed in 40 CFR 1039.102. It should be noted that as with the Tier 1, 2, and 3 standards, the Tier 4 standards include opacity requirements (see 40 CFR 1039.105) and continue the Family Emission Limit and Averaging, Banking, and Trading Program already in place. As mentioned above, it should also be noted that EPA changed the power bands for some engines between the Tiers 1 to 3 and Tier 4 standards to bring U.S. emissions limits into harmonization with European standards.

Engine Power (kW)	Application	PM (g/kW-hr)	NOx (g/kW-hr)	NMHC (g/kW-hr)	NOx + NMHC (g/kW-hr)	CO (g/kW-hr)
<8	All	0.4	-	-	7.5	8.0
8 to <19	All	0.4	-	-	7.5	6.6
19 to <37	All	0.03	-	-	4.7	5.5
37 to <56	All	0.03	-	-	4.7	5.0
56 to <130	All	0.02	0.4	0.19	-	5.0
130 to <560	All	0.02	0.4	0.19	-	3.5
	Generator Sets	0.03	0.67	0.19	-	3.5
>560	All except GenSets	0.04	3.5	0.19	-	3.5

2.1 Current U.S. Navy Diesel Engine-Powered SE

As mentioned above, the Navy currently has a wide variety of SE powered by diesel engines. In February 2000, the Naval Facilities Engineering Command, Atlantic Division, released the “Final Report for Emission Testing on Ground Support Equipment at Naval Air Stations” (the “Air Emissions Report”). This report documented the results of SE emissions testing at several Navy bases around the country. Based on this report, average emissions from the operation of selected diesel-powered SE are as follows:

Equipment Name	Type Designation	Power (kW)	PM (g/kW-hr)	NOx (g/ kW -hr)	HC (g/ kW -hr)	CO (g/ kW -hr)
Floodlight	A/M42M-2A	3	1.06	34.97	16.07	28.90
SE Tow Tractor	A/S32A-30A	50	0.40	2.36	0.21	0.91
Mid-Range Tow Tractor	A/S32A-42	60	0.32	1.05	0.48	2.28
Hydraulic Power Supply	A/M27T-5	72	0.35	12.23	1.86	1.57
Pettibone Crane	A/S32M-14	92	0.30	10.75	1.46	2.00
Mobile Electric Power Plant	NC-10C	142	0.51	10.31	1.17	1.09
Mobile Electric Power Plant [1]	A/M32A-108	142	0.42	10.18	0.74	1.09
High-Range Tow Tractor (Buddha)	TA-35	143	0.63	2.19	0.27	1.81
Air Conditioner	A/M32C-17	145	0.28	15.66	0.87	1.03
Jet Air Start Unit (GTCP-85)	A/M47-A4	156	0.64	2.04	0.25	9.31
Jet Air Start Unit (GTCP-100)	A/M47-A4	244	2.80	2.12	9.16	20.09

1. Emissions data for the Mobile Electric Power Plant (A/M32A-108) are based on data provided by the engine manufacturer, not the Air Emissions Report. The A/M32A-108 is a replacement for the NC-10C and was not in the Fleet inventory when testing for the Air Emissions Report was conducted.

As noted above, because existing engines may continue to be used, emissions levels from SE exceeding the regulatory limits described in Section 2.0 will not constitute a violation of applicable environmental law. However, many Navy facilities have air emissions permits that limit the total quantity of certain pollutants emitted from the fenceline of the facility. Therefore, reducing the quantity of emissions from SE may provide “space” for emissions from other operations and/or equipment (e.g., additional aircraft) without requiring substantial revision of the air permit. In addition, many Navy facilities are located in areas of nonattainment under the Clean Air Act’s National Ambient Air Quality Standards (NAAQS) (e.g., southern California). When an area is designated as being in nonattainment, specific air pollution control measures—up to and including imposing limits on the hours of operation of certain equipment and process lines—may be required by the permitting authority.

In 2002, NAVAIR Lakehurst was funded by the YO817 Program to prepare an Initiation Decision Report (IDR) regarding the environmental and cost impacts of SE operation and maintenance. The IDR examined utilization rates provided in a 1998 Readiness Improvement Status Evaluation (RISE) report and data obtained from Cost of Ownership of Support Equipment (COOOSE) Reports created by NAVAIR logisticians; air emissions data provided in the Air Emissions Report referenced above; and the number of diesel-powered SE based at each location as determined by a SERMIS IMRL run in 2001 in order to determine the quantity of air emissions due to the operation of diesel-powered SE from selected Navy facilities. It should be noted that air emissions data and utilization rates were not available for all diesel-powered SE listed on the IMRL; therefore, the figures above underestimate the total quantity of air emissions due to operation of diesel-powered SE at each location. Based on this IDR, the operation of diesel-powered SE resulted in the release of the following average annual quantity of pollutants from the bases evaluated:

Location	PM (lb/year)	CO (lb/year)	NOx (lb/year)	HC (lb/year)
NAS North Island	1,682	5,728	34,833	3,697
NAS Jacksonville	2,387	7,464	49,338	5,170

2.2 System Selection

This project sought to demonstrate a retrofit emissions control device for use on diesel-powered SE. Based on the emissions profiles presented above and on the current procurement schedules for the various pieces of SE, the NC-10C Mobile Electric Power Plant (MEPP) was selected as the test bed for this project. The NC-10C has a 4-cylinder, 190-bhp Detroit Diesel engine set on an angle in the bottom rear left quadrant of the shroud. The engine is exhausted through a manifold to a muffler in the top rear left quadrant of the shroud and then out the top of the unit. The manifold and muffler are located in an irregularly shaped space that is approximately 40” long by 11.75” deep, with a width of 30” at the top and 14” at the bottom. The engine is set beneath the 17” wide slope that runs from the bottom surface to a point approximately 5.25” below the top surface. The manifold rests on this slope and the muffler rests in the rectangular area of the space. The NC-10Cs were last procured during the late 1970s and are being slowly replaced by the A/M32A-108s. The TA-35 High-Range Tow Tractor (Buddha) was considered as an alternate test bed for emissions control devices that could not fit within the space available on the NC-10C. The Buddhas have a much longer exhaust system that would allow larger components to fit in line with each other; however, with the exception of PM emissions, the Buddhas already meet Tier 3 requirements.

Because Navy SE must be able to be operated on MIL-DTL-5624T (JP-5), MIL-T-83133 (JP-8), and VV-F-800 (DF2), the selected system must be sulfur-tolerant. (JP-5 may have up to 4,000 ppm sulfur; JP-8 may have up to 3,000 ppm sulfur; and DF2 may have up to 500 ppm). In addition, because of the wide variety of SE designs and the space limitations on the NC-10C, the selected system must have flexible installation requirements. Furthermore, the ideal system must provide passive emissions control with minimal operational, maintenance, and logistical requirements to ensure satisfactory reduction of emissions.

3.0 EQUIPMENT DESCRIPTION

3.1 Vendor Selection

Extensive vendor searches were conducted for a system capable of meeting each requirement outlined in Section 2.2. However, no commercially available systems were identified that could successfully meet all of these requirements, except the NC-10C MEPP.

This report summarizes the technologies examined and outlines possible future uses of these technologies. Many of these technologies can or must be combined to meet emissions requirements for future engines. Therefore, it is to be expected that one or more of these technologies will move into the Fleet along with the procurement of replacement SE. Five types of emissions control devices were examined as a part of this project:

- Non-thermal Plasma (NTP)
- Exhaust Gas Recirculation (EGR)
- Selective Catalytic Reduction (SCR)
- Diesel Particulate Filter (DPF)
- Diesel Oxidation Catalyst (DOC)

As the following table shows, each of these technologies primarily reduces the quantity of different pollutants.

Technology	Primary Pollutant Controlled			
	PM	CO	NOx	HC
NTP			X	X
EGR			X	
SCR			X	X

Technology	Primary Pollutant Controlled			
	PM	**CO**	**NOx**	**HC**
DPF	X			
DOC	X	X		X

These control technologies are often combined to reduce multiple pollutants. For example, an SCR system is often combined with a DPF or DOC system to control PM and/or CO in addition to NOx.

3.2 System Components

3.2.1 *Non-thermal Plasma Corona Discharge Device*

Non-thermal plasma (NTP) corona discharge emissions control devices typically include, but may not be limited to, the following major components:

- Stainless steel reaction chamber
- Corona electrode
- Connection to the SE's electrical system.

3.2.2 *Exhaust Gas Recirculation*

Exhaust gas recirculation (EGR) emissions control devices typically include, but may not be limited to, the following major components:

- Piping from exhaust manifold to air intake
- Valves or solenoids
- Mechanical or electronic valve control mechanism.

3.2.3 *Selective Catalytic Reduction*

Selective catalytic reduction (SCR) systems typically include, but may not be limited to, the following major components:

- Reductant storage tank
- Regulator
- Diffuser
- NOx selective catalyst
- Sensors and control system.

3.2.4 *Diesel Particulate Filter*

Diesel particulate filters (DPFs) typically include, but may not be limited to, the following major components:

- Particulate filter and housing
- Regeneration mechanism.

3.2.5 *Diesel Oxidation Catalyst*

Diesel oxidation catalysts (DOCs) typically include, but may not be limited to, the following major components:

- Housing
- Catalyst and "honeycombed" substrate.

3.3 Method of Operation

A diesel engine produces energy by injecting fuel into air that has been compressed to the temperature at which the fuel will burn. In gasoline engines, a mixture of fuel and air is burned with combustion initiated by a sparkplug. Diesel engines can be either four- or two-stroke.

In a four-stroke diesel engine, operation consists of four steps (air intake, compression, fuel injection/combustion, and exhaust), with the piston moving from the top to the bottom of its cylinder and back twice. In a two-stroke diesel engine, the same four operations are conducted with the piston moving from the top to the bottom of its cylinder and back once. Two-stroke diesel engines require a turbocharger to compress the air prior to injection into the cylinder. However, two-stroke engines typically have fewer parts overall and can provide a better power-to-weight ratio than four-stroke engines.

Combustion of diesel fuel yields a wide variety of byproducts. As described in Section 2.0, the byproducts of combustion that are currently regulated are PM, NOx, HC, and CO. Diesel emissions control devices are designed to reduce the quantity of one or more of these pollutants. PM, HC, and CO emissions are the result of incomplete combustion of fuel within the cylinder. PM consists mainly of carbon-based conglomerates that form from incomplete combustion of fuel, from the inclusion of small particles of lubricating oil, and from inorganic compounds within the fuel that do not burn. In addition, the quantity of PM formed is affected by the concentration of sulfur within the fuel, with higher sulfur concentrations resulting in higher PM formation. As the fuel is burned in the cylinder, atmospheric N_2 dissociates into N radicals. Whether NO or NO2 is subsequently formed is dependent upon the temperature of the mixture within the cylinder. Below a particular temperature, the formation of NO "freezes" and the relative quantity of NO_2 formed increases.

3.3.1 *Non-thermal Plasma*

When energy is added to a gas, the atoms of the gas begin to lose electrons (i.e., the atoms become ionized). When enough atoms lose enough electrons to significantly affect the electrical characteristics of the gas, the ionized gas is called plasma. Plasmas may be generated by a wide variety of techniques, including electrical discharge, microwave, electron beam, or radio-frequency capacitive discharge, among others.

In thermal plasmas, energy is added to the atoms, leaving the ions (atoms missing electrons) and the electrons in thermal equilibrium (1-2 electron-volts [eV], or between 20,000^{o}F and 40,000^{o}F). In non-thermal plasmas, energy is added to the electrons, leaving the electrons at a relatively high state of energy (1-10 eV) while the temperature of the gas overall remains at ambient temperatures.

Non-thermal plasmas are generated by either electron-beam or electrical discharge techniques. In electron-beam systems, electrons are created and accelerated to high energies in a vacuum chamber separate from the intended reaction chamber. The high-energy beam of electrons is introduced to the reaction chamber through a thin metal or semiconducting window. As the electrons bombard the background gas in the reaction chamber, plasma forms. In contrast, electrical discharge systems apply locally intense electric fields to a gas within the reaction chamber. Electrons within the region of the electric fields are accelerated and collide with molecules in the gas, freeing more electrons in what can become a self-propagating electron avalanche called a “streamer” or “corona.” Coronas must be quickly terminated either through external or self-quenching mechanisms because if they are allowed to continue uncontrolled, the plasma may transition to a thermal plasma condition. Corona discharge reactors typically consist of a stainless steel tube with an inner, pin-like corona electrode (often made of wolfram, copper, or stainless steel wire). The electrode is connected to an electric source.

For application to a mobile diesel engine, the NTP corona discharge system consists of an electrode centered in a reaction chamber. The reaction chamber is installed in-line with the exhaust plumbing, upstream from the muffler or another emissions control device.

Exposure of diesel exhaust to the corona discharge has the following three results. The exposure generates free radicals such as hydroxyl (OH) and ozone (O_3). Additionally, it can begin NOx reduction chemistry (e.g., a portion of NO is reduced to NO_2). Finally, it can result in the partial oxidation of HC. The creation of these free radicals improves the efficiency of the catalysts and reduces the impact of sulfur on the catalysts by binding with the sulfur and preventing it from poisoning the catalyst. The use of a non-thermal plasma system will typically reduce NOx and HC emissions directly and will reduce the emissions of PM and CO when combined with an appropriate catalyst.

NTP systems have been shown to achieve NOx reductions of 60% to 80%.

3.3.2 *Exhaust Gas Recirculation*

In EGR systems, a portion of the exhaust gas is directed back into the engine's air intake. The addition of this exhaust gas to the air/fuel mixture in the cylinder reduces the quantity of oxygen available, thus lowering the peak combustion temperature and pressure, and reducing the overall quantity of NOx produced by the engine. EGR systems have been used in automobiles since the mid-1970s.

A wide variety of EGR systems is commercially available. All of them require adding piping and valves from the exhaust to the intake, along with a valve control regime. Adding an EGR system to an engine will also require modifications to the timing of fuel injection to prevent a significant loss of power and vastly increased fuel consumption. Many EGR systems also use a DPF to prevent the introduction of PM to the cylinder.

When working properly, the EGR system will not introduce exhaust gas to the cylinder when the engine is idling, cold, or at wide-open throttle. If too much exhaust gas is introduced to the cylinder, the engine will hesitate on acceleration and idle roughly. If too little exhaust gas is introduced, the engine will begin to knock and produce additional NOx.

EGR systems can generally achieve NOx reductions of approximately 40% depending on the engine and duty cycle.

3.3.3 *Selective Catalytic Reduction*

SCR systems use a catalyst specific to NOx and inject a reductant (usually urea or ammonia) into the exhaust stream to chemically reduce NOx present in the engine exhaust to N_2 and O_2. The quantity of reductant that must be injected into the exhaust stream is dependent upon the quantity of NOx available for reaction, which is dependent upon the conditions in the engine. SCR systems have been widely used on stationary diesel engines for many years.

Most SCR systems consist of a reductant storage tank (which holds the reductant prior to use), a regulator and valve (which control the supply of reductant), a diffuser (which ensures that the reductant is adequately mixed within the stream of the exhaust gas), a catalyst (where the reduction of NOx actually occurs), and various sensors and control systems (which determine when and how much reductant is injected). Several types of catalysts may be used in SCR systems. Generally, for low temperature applications (350 to 550^{o}F), precious metal catalysts are used; for mid-temperature applications (450 to 800^{o}F), base metals such as vanadium and titanium are used; and for high temperature applications (675 to 1100^{o}F), zeolite catalysts are used.

Before an SCR system is installed, the engine must be "mapped" so that the quantity of NOx present in the exhaust is accurately related to engine conditions (e.g., revolutions per minute, throttle condition, etc.). If too much reductant is injected into the exhaust stream, the catalyst will not consume all of it and some will be emitted to the atmosphere (a condition called "ammonia slip"). If too little reductant is injected into the exhaust stream, maximum control of NOx emissions will not be achieved.

SCR systems generally result in NOx emissions reductions of between 65% and 90%.

3.3.4 *Diesel Particulate Filter*

As the name suggests, DPFs capture PM in exhaust streams through filtration. DPFs have been made from a wide variety of materials including ceramics, fiber-wound cartridges, knitted silica fiber coils, and paper. Most DPFs are muffler-like devices that are bolted in line with the exhaust system.

Over time, DPFs begin to fill up with captured particles, increasing backpressure to the engine. To remove this particulate accretion, most DPFs are "regenerated" by burning off the captured particles. A wide variety of regeneration mechanisms is available. Some regeneration mechanisms operate continuously, and some are triggered either on a regular basis whenever the engine's operations are appropriate (e.g., a particular operating temperature is reached) or by particular conditions (e.g., whenever backpressure reaches a preset amount or a set period of time has passed). In some cases, onboard or offboard heaters (either electric or fuel-burning) provide sufficient additional heat to perform regeneration. In other cases, the air intake to one or more of the engine cylinders is throttled to increase the temperature of the engine exhaust. Alternatively, a small quantity of fuel may be injected into the engine cylinders immediately after they reach top-dead-center (TDC); this additional fuel is exhausted unburned from the engine and is used to initiate combustion within the DPF.

DPFs frequently employ catalysts (either applied to the surface of the filter or injected with fuel) to reduce the energy required to achieve regeneration. DPFs using catalysts are adversely affected by the presence of sulfur in diesel fuel both because of the negative impact on catalytic action that increases the amount of energy required for regeneration and because of the increase in PM formation caused by the presence of sulfur.

DPFs have achieved collection efficiencies of between 50% and 90% of PM. Depending on the details of the regeneration cycle and the catalyst used, some DPFs may also be able to reduce the emission of CO and HC by up to 90%.

3.4.5 *Diesel Oxidation Catalyst*

DOCs use a base or precious metal catalyst to convert diesel engine emissions to less harmful forms, much as a catalytic converter does for regular automobiles. DOCs typically use "honeycombed" ceramic substrates to support the catalyst and maximize exposure of the exhaust to catalytic surfaces. Because DOCs do not restrict the exhaust flow as much as DPFs, they are significantly less likely to plug and thus less likely to require regeneration. As with catalytic DPFs, however, the presence of sulfur in the diesel fuel adversely affects catalytic performance.

DOCs can typically reduce PM by up to 50%, CO by approximately 40%, and HC by between 50% and 70%.

3.4 Overall Benefits

The control of diesel engine emissions has several potential benefits, including:

- Reduces the emission of hazardous air pollutants.
- Provides flexibility to other Navy operations adversely affected by air permit emission limits.
- Reduces permit fees associated with the emission of hazardous air pollutants.
- Provides a healthier work environment

4.0 DATA ANALYSIS

Vendors of NTP, EGR, and DOC systems who were willing to install their system in an NC-10C for this project under terms acceptable to the Navy could not be identified. Some potential vendors of NTP systems were either focused on other markets or required the Navy to commit to the procurement of their system in specific quantities prior to testing. Pacific Northwest National Laboratory developed a prototype NTP system; however, it was not available for testing during the timeframe of this project. The EGR and DOC vendors' concern was that the emissions from the two-cycle engine used by the NC-10C were so extreme (in particular the soluble organic fraction of the PM emissions) that acceptable reductions could not be achieved without significant regular maintenance of the system.

An SCR system was available. Since the recurring costs approach the cost of replacing the engine, and implementation of an SCR system would also require significant work to develop the infrastructure necessary for the delivery of a reductant, this system was not installed. A DPF originally developed for mining applications was also available; however, given the associated costs, it appeared to be less expensive to simply repower the SE with a new, compliant engine than to install this DPF.

For these reasons, no equipment was procured for this project and thus no data regarding system performance were collected. An abbreviated Cost Analysis was performed to gauge the implementation costs of one or more control technologies relative to the cost of replacing the existing engine with a compliant one.

4.1 Quantitative Analysis

4.1.1 *Cost Analysis*

Since the diesel engine emission regulations apply to new diesel engines only, existing engines may still be legally operated. Therefore, there is no broad regulatory driver requiring the Navy to implement retrofit control devices. However, by reducing the emission of pollutants from diesel-powered SE, additional "space" may be created in

Navy air emission permits for particular bases. This additional “space” will allow increased operational flexibility, permit the Navy to more effectively complete individual missions, and allow the Navy to more easily base aircraft and other equipment where needed while minimizing the impact of these basing decisions on the surrounding communities and environment—thus reducing the effect of encroachment on Navy operations.

For purposes of this cost analysis, it was assumed that the alternative to installing a diesel emissions control device was repowering (replacing the engine of) the SE. PPEP previously examined this alternative in the Low-Emissions Diesel Engine Retrofit (“Low-E Diesel”) series of projects. Based on the cost analyses associated with the Low-E Diesel projects, a retrofit program would be subject to both recurring and nonrecurring expenses. Recurring expenses included the replacement engine (meeting 1996 regulations) and labor for its installation. Nonrecurring expenses included engineering and development required to ensure that the replacement engine fits the existing SE design physically, electrically, and mechanically. These expenses varied based on the size of engine required and the amount of redesign required to fit the new engine into the existing chassis and systems. The costs for three types of SE were estimated to be as follows.

SE Name	Recurring Expenses	Nonrecurring Expenses
Hydraulic Power Supply (A/M27T-5)	$26,200	$184,000
Air Conditioner (A/M32C-17)	$46,000	$273,000
Mobile Electric Power Plant (NC-10C)	$30,000	$92,200

As mentioned above, vendors of NTP, EGR, and DOC systems who were willing to install their system in an NC-10C under terms acceptable to the Navy for this project could not be identified.

The available SCR system cost $18,500 (recurring), with $3,500 for installation (recurring) and an additional $5,000 for engine mapping (nonrecurring), for a total of $22,000 in recurring expenses and $5,000 of nonrecurring expenses. Note that bulk quantity discounts for the system and installation may be available. It should also be noted that these costs do not include the ongoing consumable cost of reductant. As mentioned above, since the recurring costs approach the cost of replacing the engine, and implementation of an SCR system would also require significant work to develop the infrastructure necessary for the delivery of a reductant, this system was not installed.

The available DPF system was priced at $75,000 for the demonstration unit and $55,000 for production units. As mentioned above, given these costs, it would be less expensive to simply repower the SE with a new, compliant engine.

4.2 Qualitative Analysis

4.2.1 *Installation*

Installation of any diesel emissions control device will require that the existing exhaust system be modified, most often by removing the muffler and installing the control device's components. In addition, some emissions control devices will require mapping the current engine (e.g., SCR) or modifying the engine's timing (e.g., EGR). Furthermore, some emissions control devices may require that a consumable (e.g., reductant or catalyst) be entered into the logistics and supply system.

4.2.2 *Training*

Training required for operation of most diesel emissions control devices is limited. In the case of SCR systems, operator training should include showing operators the location of the reductant tank fill valve and specifying the frequency of refill (recommended to be whenever refueling takes place). In the case of the NTP, EGR, DOC and DPF, operator training is limited to identifying malfunction conditions.

For maintenance personnel, a significant quantity of training is required on most systems to enable accurate troubleshooting and repair, although some systems are easier to troubleshoot than others (see Maintainability and Repairs).

4.2.3 *Maintainability and Repairs*

Failure in EGR systems will be due to one of two basic conditions. Either the valve will be open when it should be closed or the valve will be closed when it should be open. Determining why the valve is in the wrong position may require extensive troubleshooting of exhaust or EGR system components.

A wider variety of possible sources of trouble exist in DOC and DPF systems, although the most common problem encountered is likely to be cell plugging. The greatest challenge to implementing an SCR system is managing the delivery and use of a reductant. NTP systems have not been used long enough commercially to determine likely maintainability and repair issues.

All of these systems will benefit from the reductions in the sulfur concentration of fuel scheduled for 2007 and 2010 (with the exception of NTP control devices, which are unaffected by sulfur concentration).

4.2.4 *Interface with Site Operations*

EGR, DPF, and NTP systems would not require any changes to SE operation. Each system would require additional periodic maintenance (e.g., changing valves for EGR). SCR systems require that operators add urea (or another reductant) to the SE, typically at the same time the SE is refueled. Depending on the details of the system, DOC systems may require that a catalyst be added to the fuel at the time of refueling. Managing the logistics of reductant delivery was one of the primary reasons that the SCR system offered was not pursued by the PPEP for this Pre-Production effort.

4.2.5 *Future Uses*

Although the diesel emissions control devices described in this Final Report were not implemented by PPEP, it is likely that one or more of these types of devices will be used by engine manufacturers to achieve the Tiers 3 and 4 emission standards. Therefore, as multi-year SE procurement programs proceed, Program Managers must properly plan to preserve sufficient space in the initial SE design for diesel emissions control devices that will be required by out-year regulations. As an alternative, Program Managers may require vendors to ensure that the space required by engines capable of meeting future emissions standards will be no larger than the space required by the existing engine.

5.0 LESSONS LEARNED

Retrofitting diesel emissions control devices onto existing SE may prove difficult given the condition of the engines in the Fleet and the performance requirements of the control devices. However, over time these control devices will most likely begin to appear within the Fleet as new SE is procured and engine manufacturers strive to achieve the emissions limits for new diesel engines that has been established by regulation.

6.0 CONCLUSIONS

Retrofitting SE with diesel emissions control devices may provide a solution to cases of encroachment, where the objection to the preferred Navy action rests upon the quantity of air emissions from that preferred action. However, based on the following factors, retrofitting existing SE with diesel emissions control devices is not recommended at this time.

- Retrofiting existing engines is not required by current regulations.
- Procurement programs exist to replace most of the older SE, thus obviating the need for retrofit control technologies.
- Older SE engines are not always good candidates for the control technologies because the engine exhaust is “dirtier” than some control technologies can handle.
- Some control technologies (e.g., SCR) will require the development of a logistics program to supply necessary consumables (e.g., reductant).

Implementation of a diesel emissions control device retrofit program should be performed with specific regulatory and/or cost drivers in mind. These drivers will be unique to each base and may require different control device technologies (e.g., in an ozone nonattainment area, NOx is the appropriate emission to be controlled, which would result in the implementation of an SCR or EGR system as opposed to a DPF implementation program). Program Managers for multi-year SE procurement programs will need to keep future regulations in mind when evaluating technical options and the capability of a given vendor to meet Navy requirements.